PATENT SPECIFICATION 936,461

DRAWINGS ATTACHED.

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COMPLETE SPECIFICATION.

Apparatus for Depth Measurement in Cased Boreholes.

We, KOOLAJIPARI TROSZT, a body corporate duly organized under the laws of Hungary, of 11 Szent Istvan-Körut, Budapest V, Hungary, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to apparatus for depth measurement in cased boreholes.

As is known, the opening of oil and gas containing layers in oil research deep drilling—with the usual depth measuring technique—inevitably leads to incorrect depth determination. Down to about 3000 metres depth the relative rate of the error is not more than one per cent, that is, 2.5 metres at 2500 metres depth, but in depths of more than 3000 metres this relative rate grows rapidly. Such depth measuring errors often make impossible the industrial utilization of the thin oil and gas containing layers, situated at a great depth.

For ensuring adequate accuracy in depth measuring it is known to use a method in which the depth of the layers is determined in relation to the casing collars of the fixed casing tube. After lowering the casing, a locator sonde, contained in the same housing as a radio-active well logging sonde, is lowered into the well whereafter the radioactive well logging (first of all the natural gamma-logging) and the indications of the locator sonde are simultaneously recorded. The radio-active recordings made through the wall of the casing tube can be reliably identified by comparing them with the radioactive recordings or even with the electrical well logging recordings recorded in front of the casing; therefore the boundaries of the layers to be exploited, i.e. the depth of the sections to be perforated, can be defined in relation to the next casing collar which is utilised as a convenient reference whose position is known. When it is desired to open the layer, the perforator gun is lowered by a depth which is determined on the basis of the measurements made by means of a locator sonde which is mounted together with the perforator gun. The gun is stopped at said reference collar and has to be lowered or lifted only by a short distance, e.g. a few metres, depending on the direction in which the borders of the layer to be opened lie with respect to the reference casing collar. These few metres can be measured with a steel measuring tape on the well logging cable with centimetre-accuracy, and this is very satisfactory in practice. By using this technique any inaccuracy in the depth measurements can be fully eliminated and very thin oil and gas reservoir layers which are located at a great depth can be exploited.

The operation of the locator sonde previously used is based on various principles, for example, they may be electro-magnetic, mechanical, or ultrasonic systems. The ultrasonic well logging locator is not generally accurate for measuring extreme depths, because of the temperature-dependence of the electronic circuits built into the equipment which is in the bore hole.

A mechanical well logging locator requires a very precise and accurate finish. A further disadvantage of the mechanical type is that besides indicating the casing collars it also responds to any appreciable irregularity in the casing tube.

An electro-magnetic casing collar locator

which has been proposed uses two self-induction coils, one of which changes its alternating current impedance when opposite a casing collar, and this impedance change is measured on an A.C. Wheatstone bridge. The signal current is rectified by a vacuum-tube rectifier circuit which forms part of the sonde and is down the borehole. The current flows from the rectifier circuit to the recording instrument which is located on the surface by way of the same cable by means of which the alternating current of about 400 c/s frequency is sent down to the sonde for supply to the bridge. The determination of the position of the casing collar, the radio-active well logging and the perforating are all carried out by using the same equipment which is operated by a rectifying circuit. The rectifier circuit can include one or two vacuum-tubes and is located in the sonde itself.

The present invention provides apparatus for depth measurement in cased boreholes in which casing collars link successive longitudinal sections of the casing tube including a sonde having a first pair of measuring coils for measuring magnetic resistance as the sonde is moving in the boreholes, said first pair of coils being wound in opposite directions to provide an indication of the difference between the magnetic resistances measured by the pair of coils and being spaced from each other along the longitudinal axis of the sonde by a distance substantially equal to the length of a casing collar, the axis of each of said first coils being perpendicular to the longitudinal axis of the sonde and each of said first coils having a permanent magnet core having a length almost equal to the diameter of the casing tube, and one pole of the series circuit formed by the first pair of coils being earthed and the other pole connected to recording means located on the surface, the sonde also having two coil systems which serve for measuring differential magnetic resistance in the borehole when the sonde is stationary in the borehole, each coil system including an exciting coil and one of a second pair of measuring coils, said two coil systems being differentially connected with respect to each other so as to indicate the difference between the magnetic resistances measured by each of the second pair of measuring coils, the two coil systems being spaced from each other along the axis of the sonde by a distance equal to the length of a casing collar and being perpendicular to the longitudinal axis of the sonde and each being wound on a laminated iron core whose length is almost equal to the diameter of the casing tube, the exciting coils being connected to an exciting means located on the surface and the second pair of measuring coils to the recording means.

The depth of the lowermost layer in the borehole can be found in relation to any characteristic irregularity in the magnetic resistance measurements. The irregularity will be evident due to the difference in the recorded readings for two adjacent points in the casing tube which is observed during random observations or in a continuous logging programme. An irregularity may occur, for eaxmple, due to the presence of a collar, or due to a change in the thickness of the casing tube or of the magnetic characteristics of the tube. Using apparatus according to the present invention the difference in the magnetic resistance, i.e. the reductance, of the tube wall between two points may be continuously recorded. The radio-active measurement for the two depth positions of the casing tube is also recorded and the distance between the two points is always arranged to be substantially equal to the length of one collar. The depth of the desired earth layer which is recorded in a known manner on the diagram of the radio-active measurment is determined in relation to a characteristic irregularity of the magnetic difference diagram. This irregularity, as explained above, may be due to the existence of a casing tube collar, a change in the thickness of the casing tube wall or a magnetic characteristic. The perforator and the measuring sonde connected thereto for measuring the differential magnetic resistance can then be accurately lowered to the desired earth layer and the perforation carried out.

By means of the described embodiment of the invention it is possible to use a locator device utilizing an A.C. induced magnetic field to locate the casing collar and thus facilitate accurate perforation. For maximum accuracy the locator sonde should preferably be stationary during measurements. No vacuum tube need be provided in the borehole since the measurements are made using a mutual induction effect. Therefore the apparatus is simpler and more reliable since, as is known, the mechanical shock impulse caused by firing the perforator gun is detrimental to the life of vacuum-tubes.

The invention will now be explained, by way of example, with reference to the accompanying drawings in which:—

Fig. 1 shows a part of a collar locator according to one embodiment of the present invention showing the permanent magnets and the associated first pair of measuring coils;

Fig. 2 shows the connection of the inducing and measuring coil systems of the other part of the same locator shown in Fig. 1;

Fig. 3 shows typical curves of the inducing and measuring current, and the elec-

tromotive force induced in the measuring circuit;

Fig. 4 is a wiring diagram of the locator;

Fig. 5 shows one way of connecting the indicating and perforating circuits together; and

Fig. 6 shows another way of connecting the indicating and perforating circuits together.

The locator (Fig. 1) which serves to record simultaneously the position of the casing collars and also carries out the radio-active logging of the borehole, contains two permanent bar magnets 1 and 1^1, which, have their like poles pointing in the same direction, and are arranged perpendicularly to the axis of the sonde so as to be spaced from one another. The distance between the two magnets is approximately equal to the length of a casing collar. On each bar magnet a measuring coil 2 or 2^1 is co-axially mounted, the two coils being wound in opposite directions. One pole 3 of the series circuit formed by these two coils is earthed, and the other pole 4 is connected through the cable core to a recording circuit located on the surface. In conventional systems, the same cable which carries the radio-active impulses can be used as the cable for the two coils. In this case, however, the measuring coils of the casing collar locator are then connected to the control grid circuit of the output amplifier of the radio-active counting tubes, and the casing collar indications will have to be separated from the radio-active impulses both in the sonde and in the measuring and recording instrument on the surface by suitable filter circuits.

To locate the position of the casing collars prior to the perforation, the locator utilizes an alternating magnetic field. Two coil systems (Fig. 2) are provided each having a laminated soft iron core. The two systems are spaced from each other along the axis of the sonde by a distance approximately equal to the length of a casing collar. The two coil systems are arranged perpendicular to the axis of the sonde and each coil system contains one inducing coil 4 or 4^1 and one measuring coil 5 and 5^1, the coils being coaxial.

The pair of coils 2, 2^1 shown in Fig. 1 are used for measuring magnetic resistance as the locator sonde is moving down the borehole whilst the coil systems 4, 4^1, 5, 5^1 shown in Fig. 2, supplied with A.C., are used for magnetic resistance measurements when the locator sonde is stationary in the borehole.

Both the part of the locator which uses permanent magnets and that part utilising an A.C. generated magnetic field have their pair of measuring coils so connected that each resultant reading is the difference between the readings obtained by each coil of the respective pair of measuring coils, i.e. they are differentially connected. The two coils or pairs of coils have magentic fields which extend beyond the wall of the casing tube and cancel each other out. When the two coils or pairs of coils are located in a homogeneous part of the tube, the resultant magnetic resistance of their magnetic circuits is the same so that the magentic fluxes and the electromotive forces induced in the measuring coils are identical and cancel each other out.

If the coil system is located in surroundings which as regards magnetic resistance, i.e. reluctance, are non-homogeneous, e.g. close to a casing collar or a change in the wall thickness, then the magnetic resistance is different for each coil and a resulting electromotive force will be produced in the measuring circuit since one coil will be opposite the collar and the other will not.

It will be clear that by using a collar locator as described above, a comparison can be made between the magnetic resistances in the vicinity of the two coils.

In Fig. 2 the directions of the magnetic fluxes ϕ and ϕ^1 and the induced electromotive forces (e_1 and $e_1{}^1$) are shown, assuming an inducing current (i_g) of predetermined direction and increasing intensity.

The alternating current casing collar locator may be supplied with square wave or sinusoidal alternating current of constant frequency.

Since the measuring indications are recorded by the usual Deprez-D'Arsonval galvanometer system, the alternating electromotive force produced in the measuring coils has to be rectified.

In the case of square wave current a synchronous motor-driven electro-mechanical circuit breaker; a so-called well logging pulsator can be used to produce the alternating current for the inducing coil and also to rectify the current picked up by the measuring coil. This pulsator comprises two circuit breaker systems: one of the circuit breaker systems operating in the inducing circuit, the other one in the measuring circuit. In the case of pulsator feed, the frequency of the inducing current is preferably the usual one, i.e. appr. 20 cycles per second.

In Fig. 3 the variations of the inducing current i_g and the induced electromotive force e_1 are represented by solid and dashed lines, respectively, as a function of time t; the measuring current i_m flowing through the recording galvanometer is also shown. All the pulses of the measuring current which occur in the same quarter period, flow in the same direction through the recording galvanometer after rectifying. One

period of the inducing current is marked with "T" in the figure.

In Figure 3 the switching portions *s* of the measuring circuit rectifier pulsator are also indicated by a dotted line. The switching on of the measuring circuit is always effected when an inducing pulse finishes and the circuit is switched off before the next inducing impulse commences to rise in the opposite direction. By the use of such a pulsator it can be ensured that the resultant induced electromotive force in the measuring coils results in a deflecting current through the recording galvanometer of the highest possible average intensity.

The measuring circuit of the locator—regardless of the radial position of the sonde—gives no indication in collarless tube sections when the axis of the sonde is parallel to the casing tube axis, if the design of the two coil-pairs is identical and their geometrical location is symmetrical.

If the number of turns on the two inducing coils or on the two measuring coils should be different due to inaccurate winding, this difference is balanced out by adjustment.

Fig. 4 is a schematic wiring diagram in which "I" denotes the inducing circuit, and "II" the measuring circuit.

The direct voltage source II is connected through a variable resistance 12 and a milliammeter 13 to the inducing circuit side 14*a* of a pulsator 14. The output terminal of the pulsator supplies alternating current through a cable core 15 to the inducing coils 6*a* of the sonde 6, corresponding to coils 4, 4^1 of Fig. 2, an earth return being provided.

The measuring coils 6*b*, corresponding to coils 5, 5^1 of Fig. 2, of the sonde are connected through two cables 7 to the measuring circuit/rectifier side 14*b* of the pulsator 14. The rectifier supplies an output to a sensitive recording galvanometer 10 via an automatic sensitivity control circuit comprising resistances 8 and parallel damping condenser 9.

If the casing collar locator is fed with current of sinusoidal shape, the resultant sinusoidal electromotive force induced in the measuring coils is amplified by a measuring amplifier, then rectified and fed into the recording circuit. The source of current and the amplifier, as well as the rectifying circuits, are arranged on the surface.

The alternating current casing collar locator can easily be operated in association with a perforator gun. This operation of the indicating circuit and the perforating circuit can be effected by means of a common three-core cable (Figs. 5 and 6).

In the embodiment illustrated in Fig. 5 a blocking condenser 18 is connected in series with the measuring coil 16 of the locator sonde 17 and the cable 19. Cable 19 is also connected to one pole of the heater coil 20 of the perforator 21 whose other pole is earthed. Before the perforating operation is carried out the measuring circuit is disconnected on the surface, and the heater current for the perforator coil is sent down through the said cable core 19. In the event of an earth leakage in the measuring circuit the blocking condenser 18 will be effective to protect the measuring coil 16 against any detrimental effect of the perforating current.

The embodiment shown in Fig. 6 utilises a two-position relay 22 which is connected in series with the measuring coil 23 of the locator sonde 17. This relay forms part of the sonde and connects one of the measuring circuit cables 24 to the measuring coils in the so-called measuring position I and to the unearthed pole of the heater coil 20 of the perforator in the so-called perforator position II. One pole of the relay actuating coil 25 is connected through a gas-filled electron tube 26 to cable core 27 and thence to the inducing coil 28 of the locator. Under the influence of D.C., which has a greater intensity than the inducing current for the locator which is sent down through the cable core, the gas-filled tube is rendered conductive and the current flowing through the actuating coil of the relay switches the relay from the measuring position I to the perforating position II. Before perforating, the measuring circuit is disconnected on the surface, and the heater current is sent down through the commutated measuring circuit core 24 into the perforator coil. When the D.C. is removed from the cable core 27, the relay changes back to the measuring position I.

The technical characteristics of the measuring method and measuring equipment according to the invention may be summarised as follows:—

Determination of the location of the casing collars is effected in the installation according to the embodiment of the invention described by differential comparative measurement of the magnetic resistivity. This solution ensures an optimum signal to noise ratio, and high accuracy in measuring. The casing locator is reliable so far as working stability and reliability are concerned since it does not incorporate any electronic elements.

WHAT WE CLAIM IS:—

1. Apparatus for depth measurement in cased boreholes in which casing collars link successive longitudinal sections of the casing tube including a sonde having a first pair of measuring coils for measuring magnetic resistance as the sonde is moving in

the borehole, said first pair of coils being wound in opposite directions to provide an indication of the difference between the magnetic resistances measured by the pair of coils and being spaced from each other along the longitudinal axis of the sonde by a distance substantially equal to the length of a casing collar, the axis of each of said first coils being perpendicular to the longitudinal axis of the sonde and each of said first coils having a permanent magnet core having a length almost equal to the diameter of the casing tube, and one pole of the series circuit formed by the first pair of coils being earthed and the other pole connected to recording means located on the surface, the sonde also having two coil systems which serve for measuring differential magnetic resistance in the borehole when the sonde is stationary in the borehole, each coil system including an exciting coil and one of a second pair of measuring coils, said two coil systems being differentially connected with respect to each other so as to indicate the difference between the magnetic resistances measured by each of the second pair of measuring coils, the two coils systems being spaced from each other along the axis of the sonde by a distance equal to the length of a casing collar and being perpendicular to the longitudinal axis of the sonde and each being wound on a laminated iron core whose length is almost equal to the diameter of the casing tube, the exciting coils being connected to an exciting means located on the surface and the second pair of measuring coils to the recording means.

2. Apparatus according to Claim 1 in which the exciting means serves to supply sinusoidal alternating current of a constant maximum value to the exciting coils, the measuring coils of the coil systems being connected through frequency selective amplifier means and signal rectifier means to the recording means.

3. Apparatus according to Claim 2 in which the exciting means is connected to the exciting coils by a single cable and earth return circuit, and the measuring coils of the coil systems are connected to the amplifier means through a pair of cables.

4. Apparatus according to Claim 3 in which the sonde includes a blocking capacitor connected between the measuring coils and one of said pair of cables, in which one pole of a heater coil of a perforator device is connected to said one of the pair of cables and the other pole of the heater coil is earthed, means being provided for location, in operation, on the surface of the ground to interrupt the measuring coil circuit when current is fed to the heater coil through said one of the pair of cables.

5. Apparatus according to Claim 3 in which the sonde includes a relay having a movable contact which is movable between two fixed contacts, the movable contact being connected to one of said pair of cables, one of the fixed contacts being connected to the side of the measuring coils remote from the other of the pair of cables and the other of the fixed contacts being connected to one pole of a heater coil of a perforator device, the other pole of the heater coil being earthed, the coil of the relay being connected through a gas-filled electron tube to said single cable, and said movable contact being capable of being switched from said one fixed contact to the other fixed contact as a result, in operation, of a switching current flowing along the single cable through the electron tube and through the relay coil.

6. Apparatus for depth measurement in cased boreholes, constructed, arranged and adapted to operate substantially as herein described with reference to Figures 1 to 4 of the accompanying drawings.

7. Apparatus for depth measurement in cased boreholes, constructed, arranged and adapted to operate substantially as herein described with reference to Figures 1 to 5 of the accompanying drawings.

8. Apparatus for depth measurement in cased boreholes, constructed, arranged and adapted to operate substantially as herein described with reference to Figures 1 to 4 and Figure 6 of the accompanying drawings.

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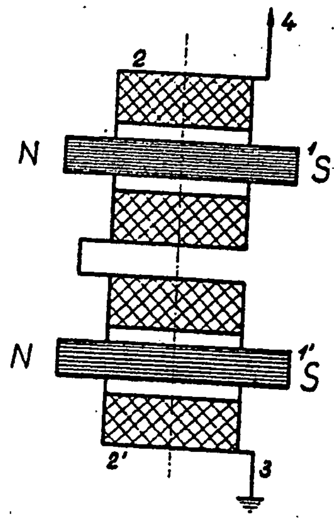


Fig.1

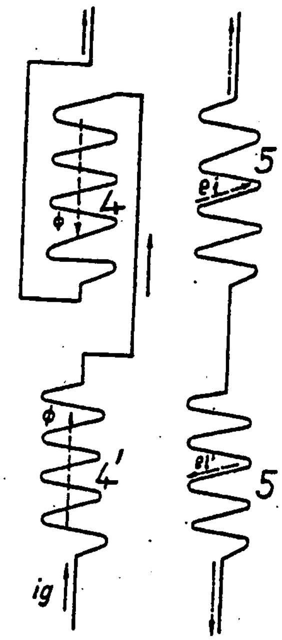


Fig.2

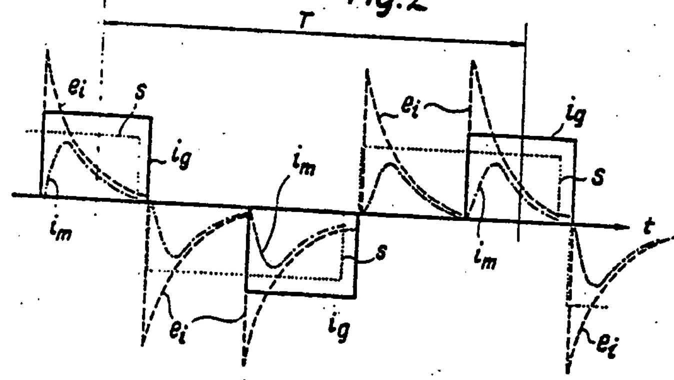


Fig.3

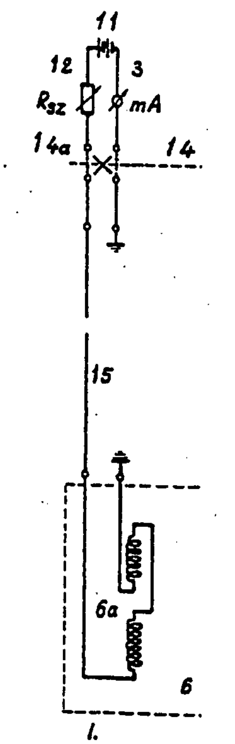
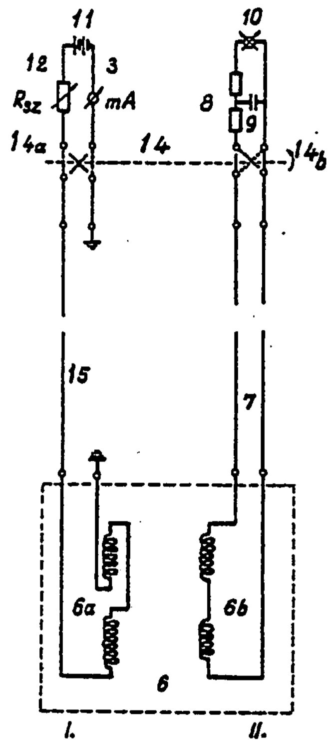


Fig.4

936461 COMPLETE SPECIFICATION
4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheets 1, 2, 3 & 4



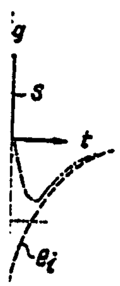


Fig. 4

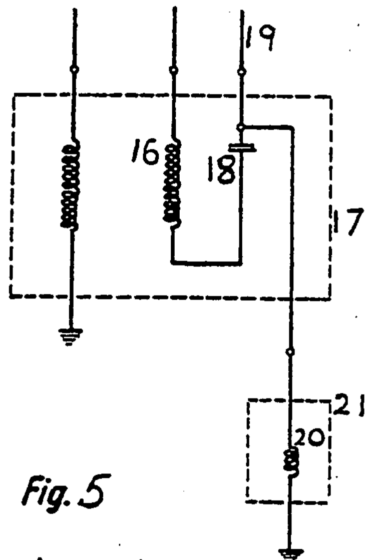


Fig. 5

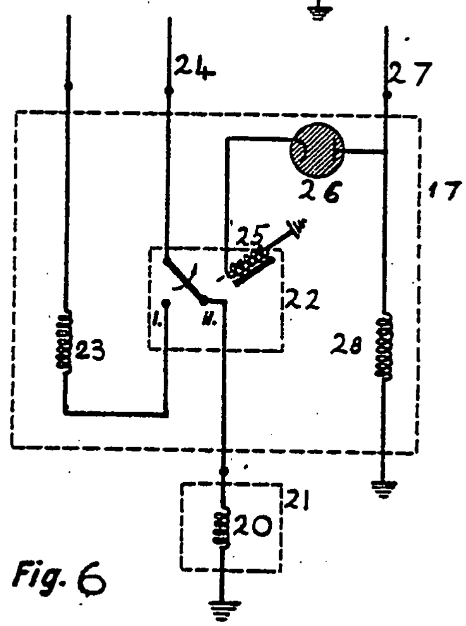


Fig. 6

936461 COMPLETE SPECIFICATION
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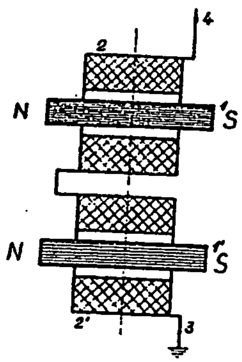

Fig.1

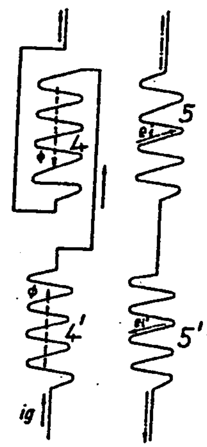

Fig.2

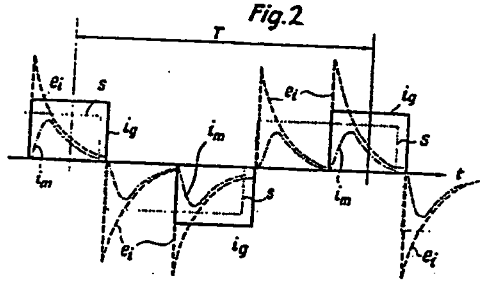

Fig.3

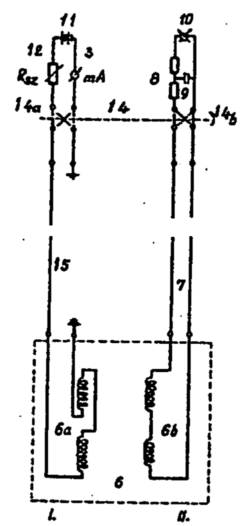

Fig.4

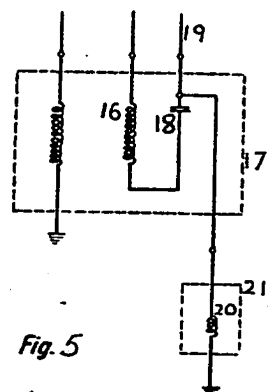

Fig.5

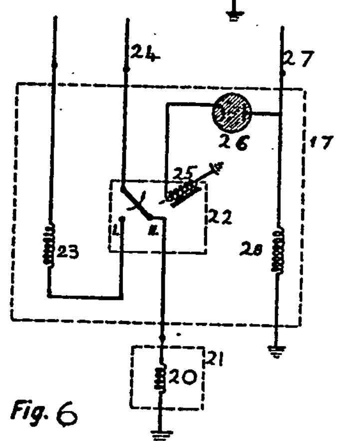

Fig.6